FINITE ELEMENT STRESS ANALYSIS OF MIDLIFE REFIT PENETRATIONS IN QUEST BOTTOM STRUCTURE

Neil G. Pegg

Canada

DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

9 GROVE STREET

P.O. BOX 1012
DARTMOUTH, N.S.
B2Y 3Z7

TELEPHONE
(902) 426-3100

CENTRE DE RECHERCHES POUR LA DÉFENSE ATLANTIQUE

9 GROVE STREET

C.P. BOX 1012
DARTMOUTH, N.É.
B2Y 3Z7

National Defence
Research and
Development Branch

Défense nationale
Bureau de recherche
et développement

FINITE ELEMENT STRESS ANALYSIS
OF MIDLIFE REFIT PENETRATIONS
IN QUEST BOTTOM STRUCTURE

Neil G. Pegg

September 1997

Approved by: R.W. Graham
Head / Hydronautics Section

TECHNICAL MEMORANDUM 97/249

**Defence
Research
Establishment
Atlantic**

**Centre de
Recherches pour la
Défense
Atlantique**

Canada

Abstract

This technical memorandum describes the finite element stress analysis of proposed major penetrations in the midship bottom structure of CFAV QUEST. This work was undertaken for two purposes. The first objective was to determine if the proposed modifications would have any detrimental effect on the structural integrity of QUEST's hull structure. The second objective was to demonstrate and validate the new capabilities in the global-detail finite element analysis code VAST DSA (Vibration And STrength, Detail Stress Analysis) developed as part of DREA's Ship Structures project. The results indicated that the penetrations will cause significant increases in stress but these values are still well within acceptable design limits. VAST DSA proved to be an efficient process for undertaking the complex global-detail top/down finite element analysis. This complex analysis was undertaken within a reasonable time frame which will be further decreased in future with improvements in data management and model generation.

Résumé

Le présent document technique décrit le procédé d'analyse par éléments finis des contraintes qui pourraient être produites par les importantes pénétrations de la structure de fond projetées sur la partie centrale du NAFC QUEST. Ces travaux ont deux objectifs. Ils visent d'abord à déterminer si les modifications proposées peuvent avoir un impact négatif sur l'intégrité structurale de la coque du QUEST. Ils doivent ensuite servir à démontrer et à valider les nouvelles capacités du code VAST DSA (analyse des contraintes par détails) développé dans le cadre du projet sur les structures des navires du CRDA et mis au point pour analyser des éléments finis par détails globaux. Les résultats indiquent que la pénétration risque de causer des augmentations importantes des contraintes mais que ces valeurs sont encore dans les limites de conception acceptables. Le procédé VAST DSA s'est avéré un outil efficace pour le difficile programme d'analyse descendante des éléments finis par détails globaux. C'est grâce à cette technique qu'une analyse aussi complexe peut être effectuée dans des délais raisonnables, délais qui devraient être réduits davantage par les améliorations apportées à la gestion des données et à la génération des modèles.

Finite Element Stress Analysis of Midlife Refit Penetrations in QUEST Bottom Structure

by

Neil Pegg

Executive Summary

Introduction

In recent years, ship structural analysis has progressed to what has been termed 'rational methods' or more correctly, methods which are based on direct physical principles rather than methods based on past experience. This has occurred largely as a result of rapid increases in computer power allowing extensive application of numerical methods on inexpensive desktop computers. The finite element matrix method of structural analysis has been the main tool applied by the various agencies involved in ship structural analysis. DREA has been developing finite element methods for ship structural analysis for many years with the most recent product being the DSA (Detail Stress Analysis) code for analysis of stress in ship structural details. The DSA code has been developed cooperatively with Martec Ltd of Halifax, N.S. and a first version has been successfully marketed for use by ship classification societies for ship structural analysis. This TM describes the DSA method and its application to proposed midlife design modifications for CFAV QUEST which consist of several significant penetrations through the midship bottom structure to house sonar gear.

Principal Results

Static stress analysis using a design wave was undertaken on a full finite element model of QUEST followed by top/down finite element analysis of two detail structure areas in the midship bottom region incorporating the proposed penetrations. The analysis showed that there are significant increases in stress resulting from the penetrations but that the stress values are still well below acceptable design limits. The DSA code proved to be an efficient process for undertaking this complex structural analysis, allowing results to be produced within the one month time frame required for design evaluations.

Significance of Results

In the past, the process of undertaking finite element stress analysis of structural details within a global model of the full ship has been a prohibitively time consuming process. The time to prepare data and undertake the various steps in the process, and until recently, the computer time and hardware requirements, all contributed to a desire to avoid undertaking

finite element analysis even though it was recognized to be the best solution. The work described in this report has proven that complex finite element analysis can be undertaken in a timely manner. This analysis took approximately one person month. This time will be further significantly reduced by ongoing developments in database management and detail structure modelling. The computer run time for the analysis was on the order of one hour on a 100 MHz Pentium laptop PC. This method is being used in the DRDB (Defence Research and Development Branch) major project ISSMM (Improved Ship Structural Maintenance Management) to provide efficient rational structural analysis capability to assess ship structural integrity in damaged or degraded conditions.

Future Plans

The DSA code will continue to be improved. The most significant advancement will be a relational object oriented database of ship structure which will facilitate the automation of finite element model generation for structural details. A database for the Halifax Class patrol frigate is being developed as part of the ISSMM project and mechanisms to simplify creation of databases for other Canadian Forces (CF) vessels are being developed. This development should reduce the time necessary to undertake the type of analysis described in this report to only a few hours. Overall, this will greatly improve the CF's capability to undertake rational, timely assessment of ship structural integrity.

Table of Contents

List of Figures

1. Introduction

As part of the midlife refit of CFAV QUEST, several significant penetrations (the largest being 40.75 inches in diameter) through the bottom structure near the keel are being implemented for various sonar instrumentation. Additional structure including tanktops, bulkheads and collars were designed around the penetrations to compensate for lost material and to enclose the instrumentation. The bottom structure of a ship in the midbody keel region is critical to the overall hull girder strength as it often experiences the highest stress levels during seaway operations. Stress analysis was not required as part of the midlife refit contract; however, large penetrations can have significant effect on structural integrity and detailed analysis was warranted. In discussions with the QUEST refit project office and the prime contractor, DREA offered to apply advanced finite element analysis techniques to determine the stress levels resulting from the penetrations before they were implemented.

The analysis methods applied to this problem are under development by DREA and this task served as a useful demonstration and validation exercise. The methods use the DND developed finite element code VAST [1] in conjunction with the commercial global ship analysis code MAESTRO [2] in a combined analysis program called DSA (Detail Stress Analysis). The DSA program is described in this report, followed by brief descriptions of the applied design loads supplied by the QUEST midlife contractor, a description of the detail and global models, and the stress results.

2. DSA Top-Down Finite Element Analysis

Finite element modelling of a large portion of a ship in a form suitable for stress analysis of structural details is prohibitive due to the effort required to create the models and the resulting solution requirements. A means to overcome the difficulties associated with finite element modelling for ship structural detail analysis lies in applying multi-step modelling techniques involving coarse mesh models of the overall ship structure and detailed meshes only of the specific areas of concern for detailed stress analysis. The coarse mesh (or global) model is used to develop the overall structural response to a design load defined for the entire hull structure. Results of the overall structural response are then applied to the boundaries of the detail mesh regions to determine stress values for fatigue calculations or forces for local component failure assessment. This approach is called 'top-down' analysis.

A collaborative effort over the past two years by DREA and Martec Ltd of Halifax, has resulted in the production of the DSA (Detail Stress Analysis) capability for ship structures. DSA provides a semi-automated capability to undertake top-down finite element analysis of structural details within a large structure such as a ship. Refined finite element meshes of ship structural details suitable for detailed stress analysis are embedded into a coarse mesh finite element model of the entire ship structure. This is accomplished

by transferring displacements at the boundaries between the coarse and fine mesh regions through application of displacement constraint equations.

The analysis of QUEST described in this report has used the DSA code with a MAESTRO global model of QUEST to provide the global top level displacements and
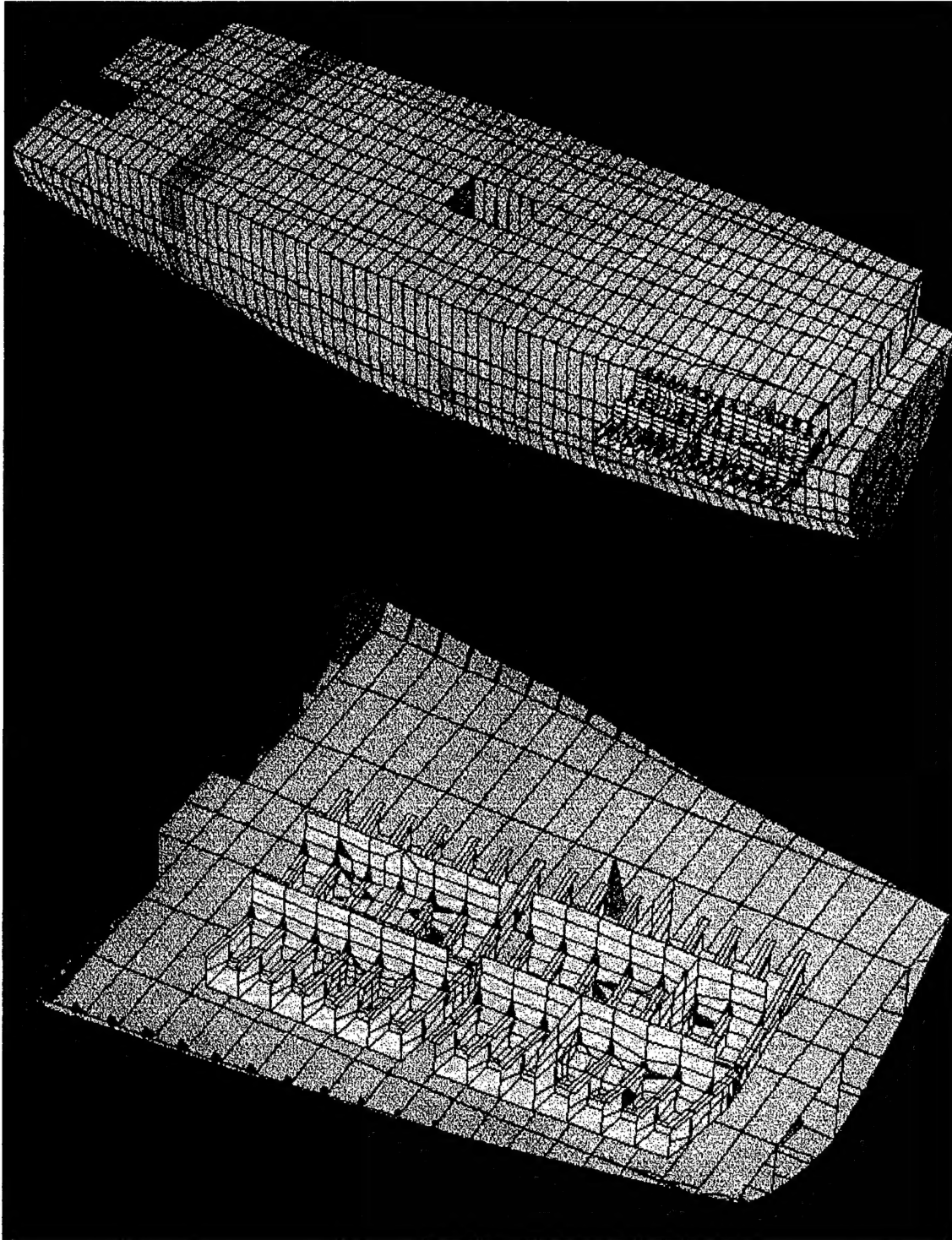

Figure 1: DSA Application to Detail Penetration Areas on QUEST Global Model

VAST models of the two detail areas at frames 40 and 48 which include the proposed hull penetrations. Figure 1 shows the two detail mesh areas inserted into the global MAESTRO model of the hull. Note that the two detail models are separated by only one frame spacing, so that they may appear as one larger model. The separation can be seen in the lower figure.

The DSA capability has met a recognized need in the ship structural analysis field in applying modern computer technology to ship structural design and analysis. DSA has been adopted by the ship structural design code MAESTRO to produce a product called MGDSA, is being used by one international ship classification society (Bureau Veritas, the French class society currently has 70 tankers modelled with DSA) and is under consideration by others, and will form the main analysis engine of the DND program on Improved Ship Structural Maintenance Management (ISSMM) [3].

3.   Loads

The sea environment produces a complex load system on a ship structure. Modern numerical methods now allow for more realistic modelling of the actual sea load. While design methods are beginning to implement these more complex load models, most design is still undertaken by an artificial design wave loading condition. The design wave method was used for QUEST by the midlife design contractors. The longitudinal strength report supplied by the contractors [4] outlines the new structural section modulus, the design wave condition, the new weight distribution and the resulting midship bending moments and shears. The applied bending moment was 9083 LT-ft [4]. Using this value of bending moment and the midship moment of inertia value of $343400.0 \ in^2 ft^2$ [4], a global field stress in the keel plating of only about 1,000 psi can be calculated using beam theory. This is a very low value in comparison to the material yield stress of 38,000 psi.

For the DSA analysis, the design wave load was applied to a global MAESTRO model. The load was applied as a static balance of displacement forces and buoyant forces from the design wave which was 235 feet in length and 11.75 feet in height (crest-to-trough) in a hogging condition (crest at midships)[4].

4.   Global Finite Element Model

The global finite element model was created with MAESTRO and includes all frames and plating and major longitudinal structure and correctly models the stiffness of the overall hull girder. The global model of the full ship is shown in Figure 2, with the two penetration detail models imbedded.
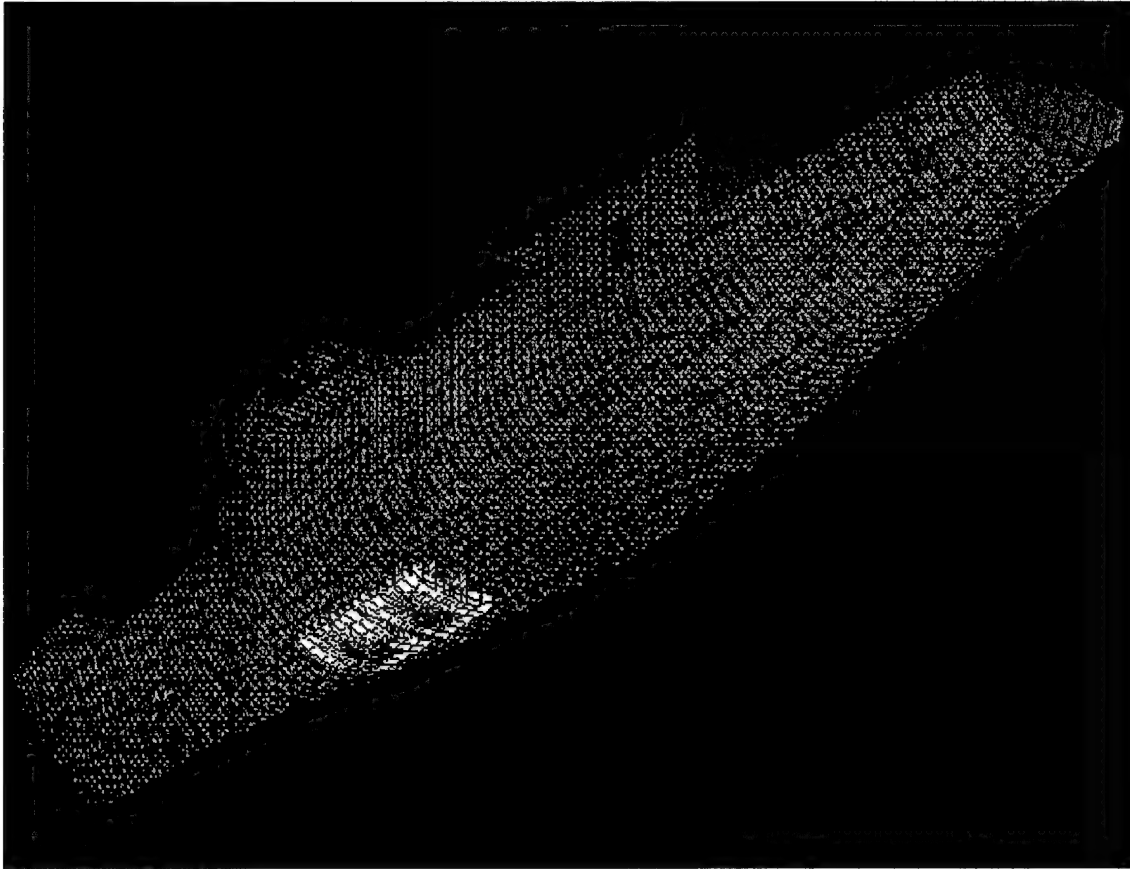
Figure 2: Global Finite Element Model of the Full QUEST Hull with Penetration Models Inserted

5. Detail Finite Element Models

Refined finite element meshes incorporating the penetrations had to be developed to assess the stress distribution in the DSA analysis. Creating detail finite element models is a time consuming process and DREA is developing improved modelling capabilities specifically for ship structure. The program Hypermesh [5] was used to create reasonably refined models of the two penetration areas at frames 40 and 48, including the compensating structure added around the hull openings. Figure 3 shows a plan view of the penetrations and two views of the detail mesh at Frame 48 are shown in Figure 4 (further views of the detail meshes at Frames 40 and 48 can be seen in the stress results of Figures 7 and 8 later in the report). An additional model with much more extensive refinement in the areas of the openings but excluding the added structure except for the compensating collars was also developed for the penetrations at Frame 48 and is shown in Figure 5.
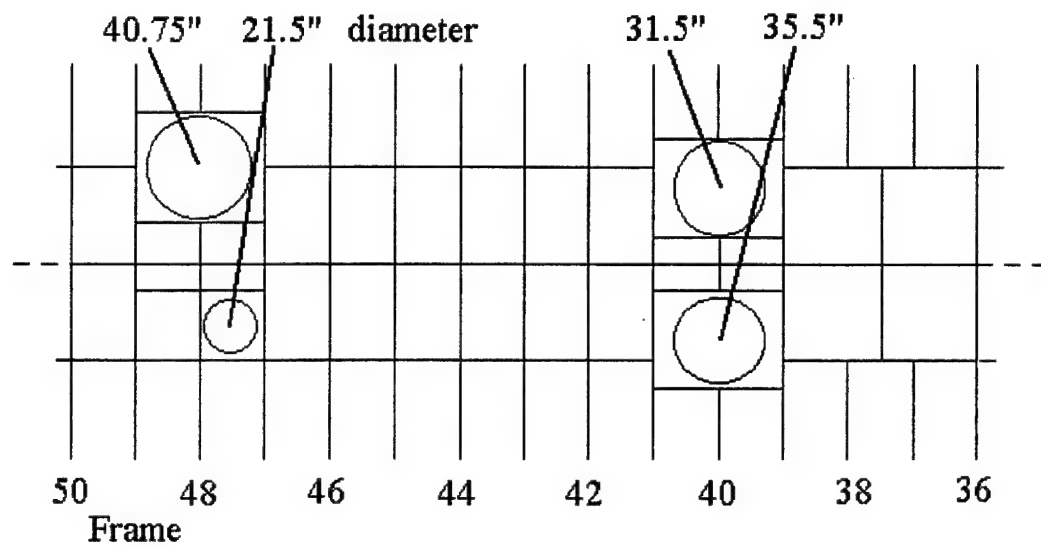
4

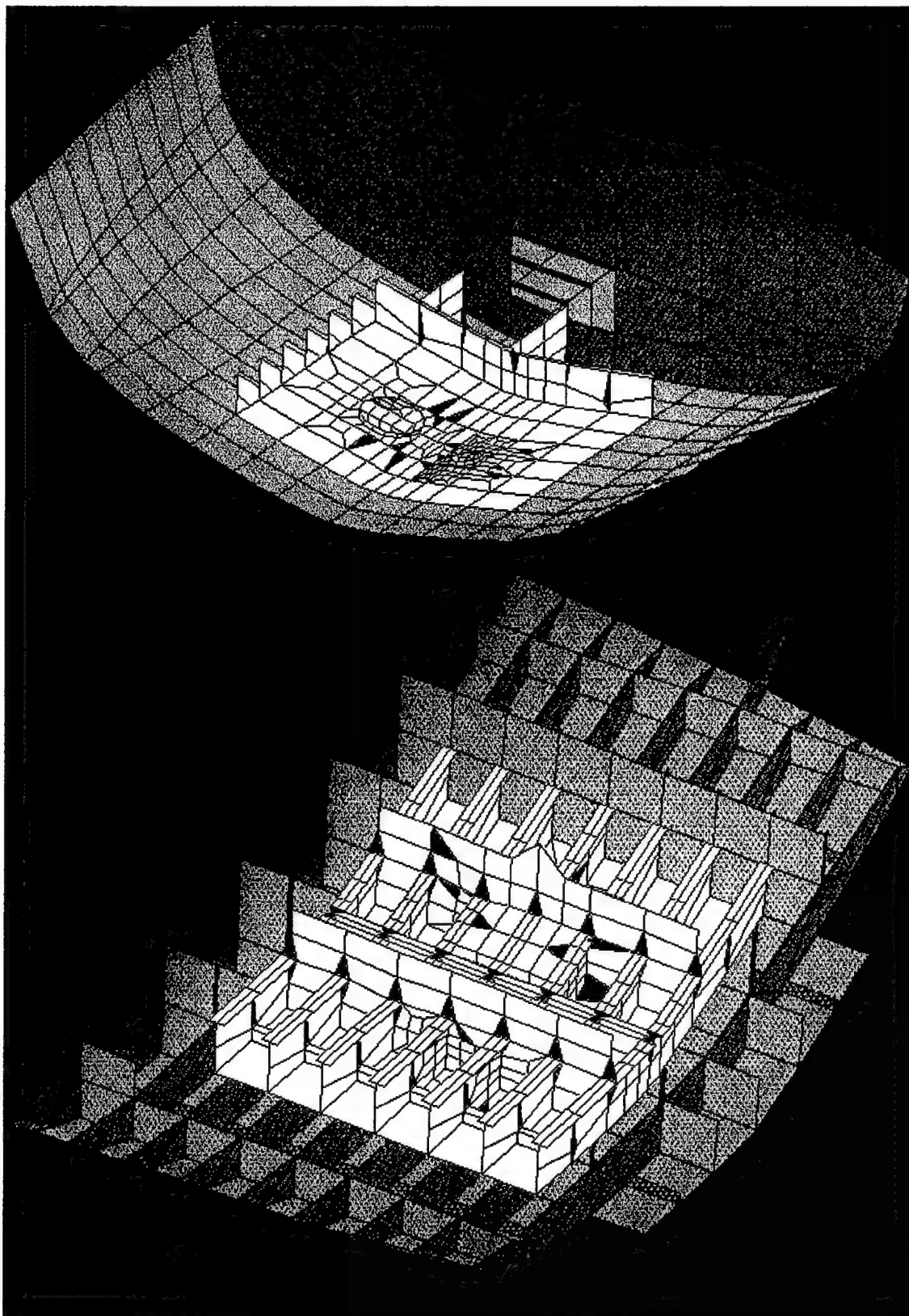**Figure 3: Plan View of Penetrations at Frames 40 and 48**

Figure 4: Detail Finite Element Mesh of Penetrations at Frame 48 (Model 48a)
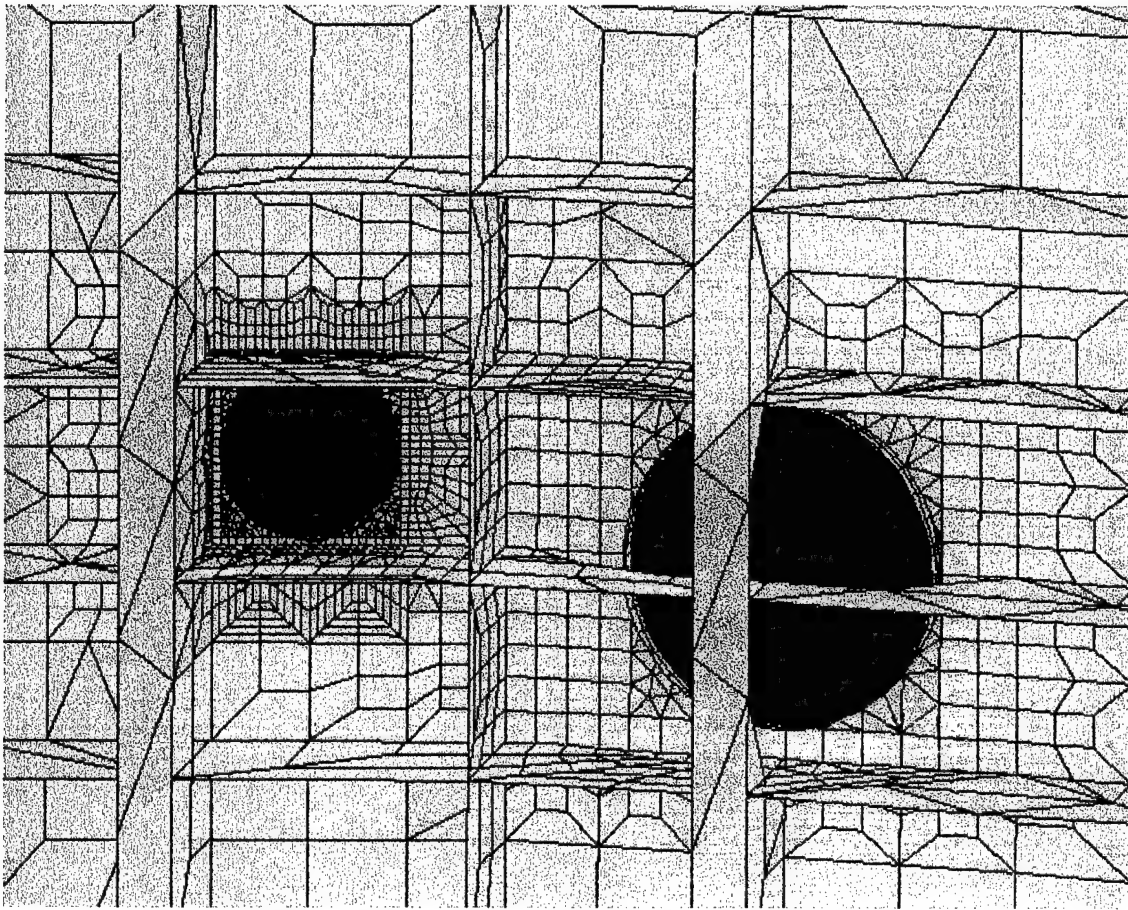
Figure 5: Extensively Refined Finite Element Mesh at Frame 48 (Model 48b)

6. Stress Results for Global Hull Model

Figure 6 shows the von Mises stress in the bottom hull plating for the global model with the design wave load. The average field stress from this model is about 3400 psi in the vicinity of where the penetrations are to be implemented. The MAESTRO global model gives field stresses which are considerably higher than the beam theory calculation (or non finite element analysis) using the input bending moment and section modulus from the contractor report [4]. Report [4] includes most of the midship hull and superstructure in its section modulus calculation whereas the finite element analysis shows that only about half of the total structure at midship contributes to resisting longitudinal bending. There is also considerable shear lag in the bottom of the ship which the beam theory calculations do not include. The global finite element model with the design wave load is used for the remainder of the discussion in this report since it gives conservative results in comparison to the beam theory calculations.
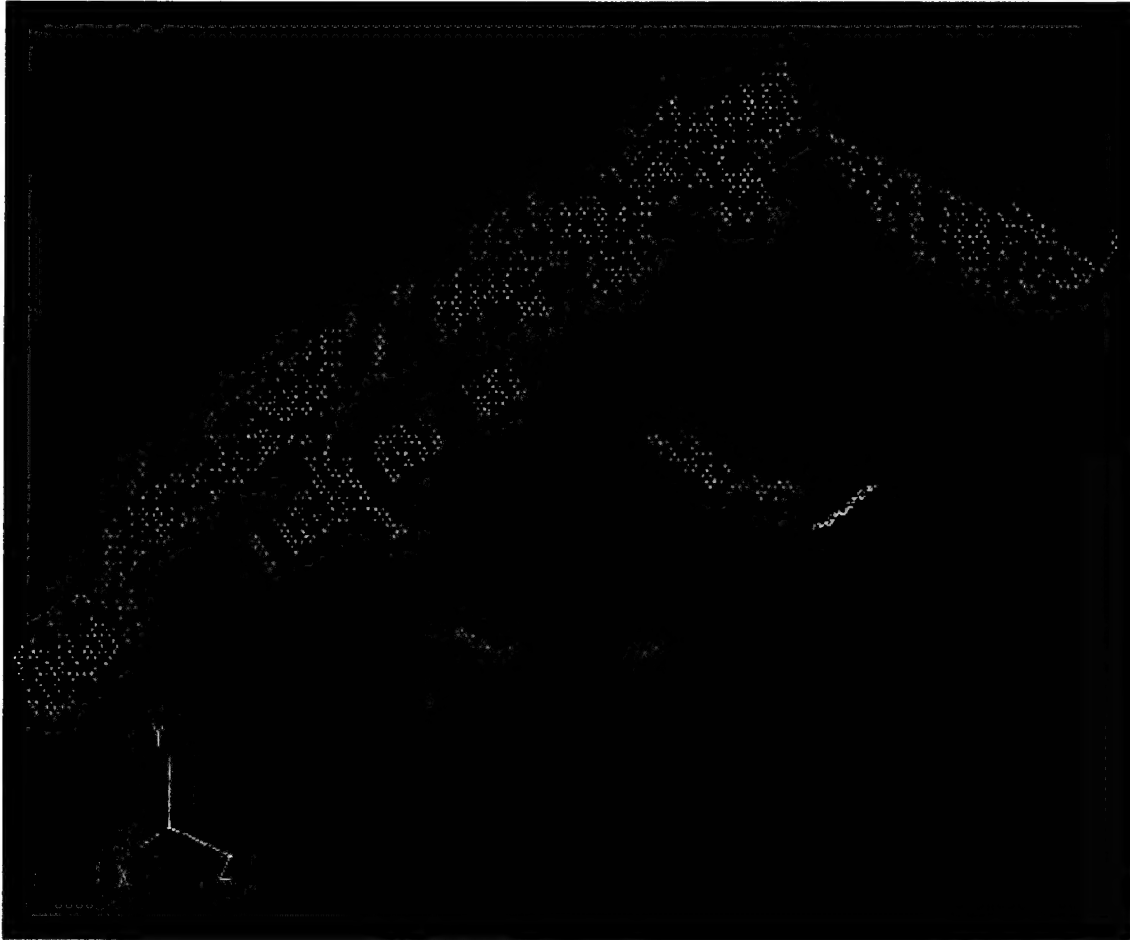
7

Figure 6: Von Mises Stress in the Bottom Hull Plating for the Global Model with the Design Wave Condition - Average Field Stress 3400 psi

7. Stress Results of Penetrations at Frame 40 (Model 40)

Figure 7 shows the stress results for the detail model at frame 40 (model 40) from the design wave load applied to the global hull model. Results indicate maximum von Mises stress levels on the order of 5100 psi with maximum longitudinal stress of about 6000 psi (longitudinal stress component only). These maximums occurred at the edge of the cutout. This is only a modest increase in stress resulting from the penetration of about 1.5 over the field stress in the global model. The yield stress of QUEST hull plate is 38,000 psi which means that these stress values at the penetrations are not of concern for strength or fatigue, based on the applied design wave load.
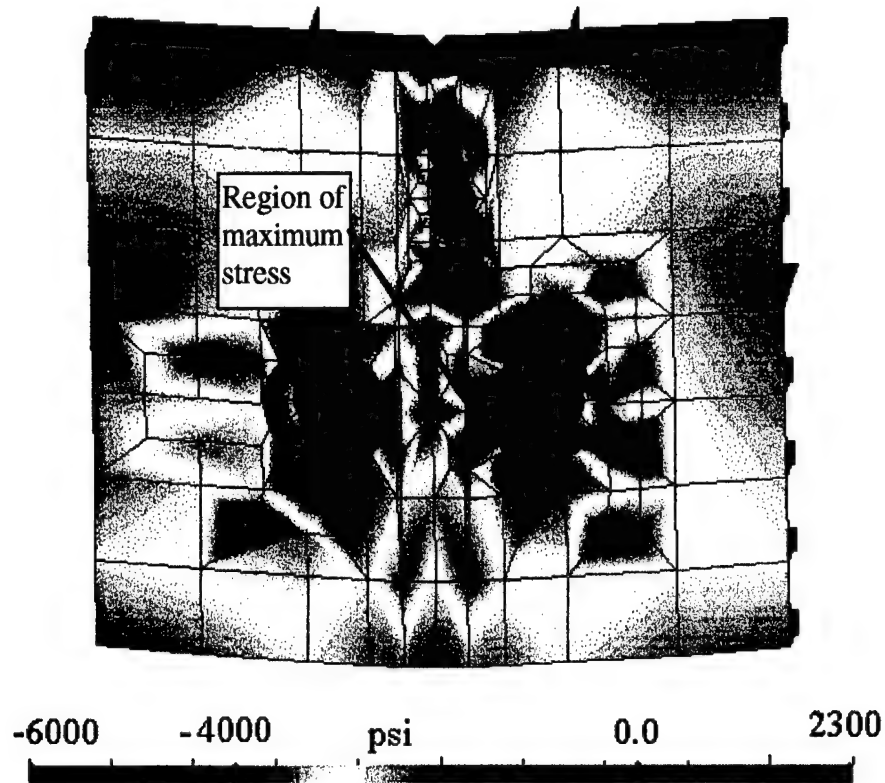
8

-6000   -4000   psi   0.0   2300

Figure 7: Finite Element Model and Von Mises Stress Patterns in Bottom of Detail Model at Frame 40

8.   Stress Results of Penetrations at Frame 48 (Model 48a)

Figure 8 shows the stress results for the detail model at frame 48 (model 48a) from the design bending wave load applied to the global hull model. Results indicate stress levels on the order of 7000 psi around the penetration. This is an increase in stress resulting from the penetration of about 2.0 over the field stress in the global model, and again, these stress values at the penetrations are not of concern for the QUEST material. A similar stress value was found at the connection of frame 47 and the longitudinal bulkhead (floor) plating just in front of the penetration. Again the stress is not of concern in comparison to the material yield stress but care should be taken in finishing of the detail areas.
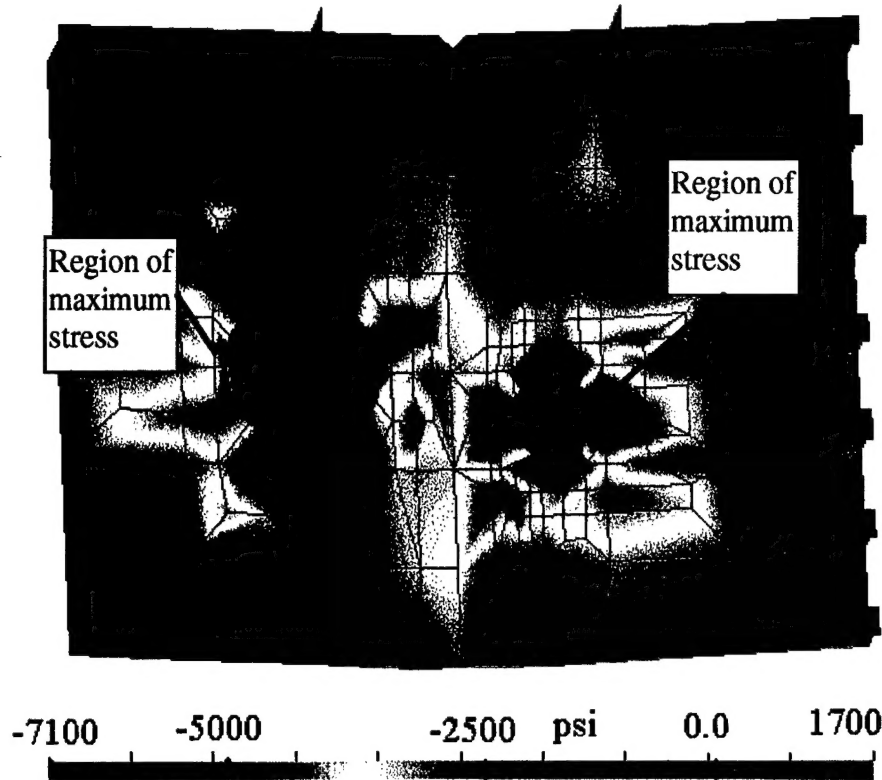
Figure 8: Model and Von Mises Stress Patterns in Bottom of Detail Model at Frame 48 - maximum value at 7000 psi

9. Stress Results for Very Detailed Model at Frame 48 (Model 48b)

A detail stress analysis of Frame 48 without the compensating structure (but including the collar plate) and with a much more refined mesh gave stress values of about 10000 psi at the penetration edges. This is a conservative result and is still well below the common design limit of half of the yield stress (19,000 psi). Figure 9 shows the stress plots from this analysis.

10. Conclusions

This report described an investigation into stresses resulting from large penetrations in the bottom structure of CFAV QUEST which have been proposed as part of the midlife design. Owing to the effort required to produce the finite element models of the hull and penetration details, different levels of analysis were undertaken as the models became available. Stresses in the bottom structure of QUEST resulting from the penetrations are considerably below allowable design limits based on static balance on a design wave.
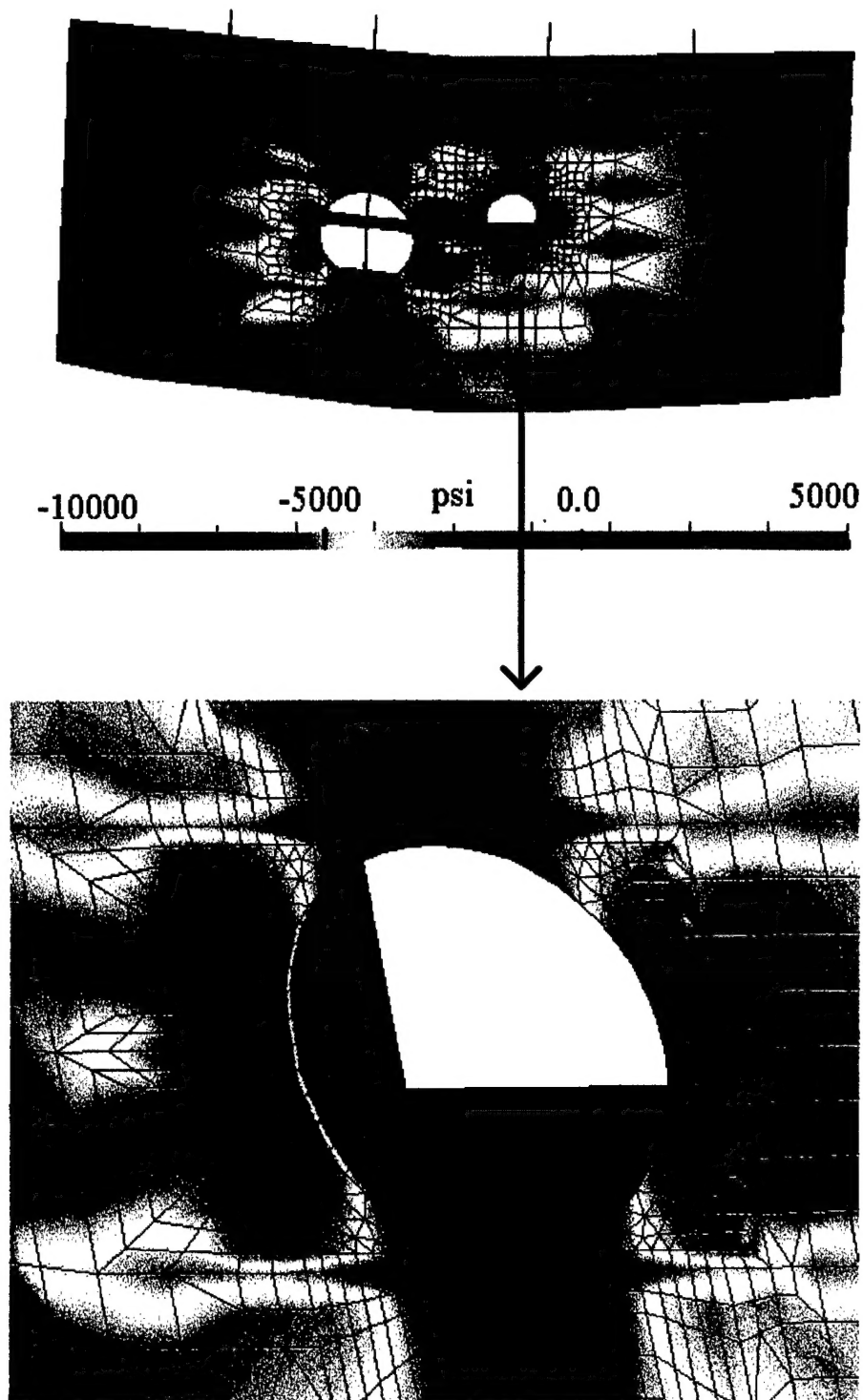
10

Figure 9: Stress Patterns in Very Detailed Model at Frame 48 - maximum value 10000 psi in lightly shaded areas at edges of holes (Note: fore/aft is vertical on page)

Using the most conservative assumptions, the maximum stress at the penetration edge is approximately 10,000 psi which is only about 25 percent of the yield stress of the QUEST material.

The global hull stress results show greater difference between beam theory 'hand' calculations [4] and the finite element analysis for balance on a wave results than would be expected. The section modulus and design midship bending moment from the contract design documents[4] produce a beam theory field stress of about 1000 psi in the keel plate, whereas the finite element results give an average keel plate stress of about 3400 psi. This may be explained by the fact that QUEST is a short deep beam for which conventional beam theory calculations are less accurate, and that the hand calculations in [4] seem to include all of the superstructure as contributing to longitudinal strength in the calculation of the section modulus, which would produce lower stress values.

The second objective of this work, to demonstrate and validate the DSA code was met. This was a comprehensive analysis and was undertaken efficiently by the DSA program. Areas where further improvement are necessary were identified. This was primarily in detail model generation. Work is underway at DREA to simplify detail model generation of common ship details such as cutouts with collars as were used in this work. The development of a relational database between the global and detail structures and structural scantling and material information is also being developed. The work described here for QUEST required about one person month of effort. This is not an unreasonable time for this type of analysis which would have been prohibitively time consuming and costly before the development of the DSA code. The next phase of development incorporating the new modelling and database structure should reduce the time required by an order of magnitude.

The results of this work have been submitted to the QUEST midlife refit design contractor for use in evaluating the structural integrity of the penetration designs.

References

1. 'Vibration and Strength Analysis Program (VAST): User's Manual - Version 5', Martec Ltd, Halifax, N.S., 1989.
2. 'MAESTRO - Method for Analysis Evaluation and Structural Optimization, User's Manual - Version 6.0', distributed by Ross McNatt Naval Architects, Annapolis, MD, July 1992.
3. Pegg N.G, Gibson S., 'ISSMM - Application of Advanced Analysis Methods to the Life Cycle Management of Ship Structures', Advances in Marine Structures III, Dunfermline, Scotland, May, 1997.
4. Haggar T., 'Revised Weight Budget Estimate and Longitudinal Strength Assessment for CFAV QUEST', November 1, 1996
5. Hypermesh Documentation, Version 2.0, Altair Finite Applications, Troy, MI, 1995.

DOCUMENT CONTROL DATA
(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified) ·

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared. e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)	2. SECURITY CLASSIFICATION (Overall security of the document including special warning terms if applicable.)
Defence Research Establishment Atlantic P.O. Box 1012, Dartmouth, N.S. B2Y 3Z7	Unclassified

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C.R or U) in parentheses after the title.)

Finite Element Stress Analysis of Midlife Refit Penetrations in QUEST Bottom Structures

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

PEGG, Neil G.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.)	6b. NO. OF REFS. (Total cited in document.)
September 1997	20	5

6. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Memorandum

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the reseach and development. Include the address.)

Defence Research Establishment Atlantic
P.O. Box 1012, Dartmouth, N.S. B2Y 3Z7

9a. PROJECT OR GRANT NUMBER (If appropriate. the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NUMBER (If appropriate, the applicable number under which the document was written.)
Project 1gc 11	

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number mrst be unique to this document.)	10b. OTHER DOCUMENT NUMBERS (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
DREA Technical Memorandum 97/249	

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; futher distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic annoucement of this document. This will normally correspond to the Document Availability (11). However, where futher distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)